Marine Fish and Invertebrate Atlas: Summarizing Geographic Distribution and Population Indices in the Scotian Shelf and Bay of Fundy (1970-2020)

Daniel Ricard and Catalina Gomez

Science Branch
Gulf Region
Fisheries and Oceans Canada
Moncton, New Brunswick, E1C 5K4, Canada

Science Branch
Maritimes Region
Fisheries and Oceans Canada
Dartmouth, Nova Scotia, B2Y 4A2, Canada

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by

Daniel Ricard [1] Catalina Gomez [2]

[1]Science Branch
Gulf Region
Fisheries and Oceans Canada
Moncton, New Brunswick, E1C 5K4, Canada
[2]Science Branch
Maritimes Region
Fisheries and Oceans Canada
Dartmouth, Nova Scotia, B2Y 4A2, Canada

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ABSTRACT

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The summer groundfish research vessel survey on the Scotian Shelf and in the Bay of Fundy started in 1970 and was designed to measure the distribution and abundance of major commercial fish species. Over time, additional information on non-commercial species was collected, and allowed considerable insight into ecosystem function and structure, as documented in many primary publications whose analyses used the survey data. The same groundfish survey database has also been used to produce species status reports, atlases of species distribution and remains an essential source of information for stock assessments in the Maritimes Region of Fisheries and Oceans Canada. This report builds on previous work and former atlases by updating a comprehensive suite of indices to assess population status and environmental preferences of 104 species. For each species, trends in geographic distribution and biomass or abundance were plotted. The spatial extent of distribution was plotted over time to gauge how the area occupied has changed. The relationship between abundance or biomass and spatial extent reflected whether the species distribution expands when abundance or biomass increases. Length frequencies over time depicted any changes in mean size. The plots of condition over time revealed whether individual fish are fatter or thinner than their long term mean. Depth, temperature and salinity preferences were estimated to gauge the range of suitable environmental parameters for each species. Finally, for each stratum, the slope describing how local density varies with regional abundance was estimated.

RÉSUMÉ

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1 Introduction

The summer (July-August) groundfish research vessel survey on the Scotian Shelf and in the Bay of Fundy was started in 1970 by Fisheries and Oceans Canada Maritimes Region. The survey was originally designed to measure the distribution and abundance of major commercial fish species. Over time, information on non-commercial species was also collected. The groundfish survey database storing the information collected during the annual survey provides the main source of fisheries-independent information for marine species in the region. This information is routinely used to support stock assessments, to produce species status reports and has been previously used to publish atlases of species distribution.

The current document is an update of an earlier report (Ricard and Shackell 2013) that built on former atlases by updating a comprehensive suite of derived indices for 104 species to assess population status and environmental preferences. The information collected during the survey is stored in a relational database management system archived at Fisheries and Oceans Canada Maritimes Region which contains detailed information about the sampling locations and the associated catch. Tow-level survey data is also publicly available from the Ocean Biogeographic Information System (DFO 2016) and (FGP link TBA). The present atlas follows on the work done by Fisheries and Oceans colleagues from the northern Gulf of St. Lawrence (Bourdages and Ouellet 2012), southern Gulf of St. Lawrence (Benoît et al. 2003) and on earlier work in the Scotian Shelf (Simon and Comeau 1994; Horsman and Shackell 2009).

To facilitate updates and foster collaboration on the analyses of the survey data, the R computer code (R Core Team 2020) necessary to extract, update and reproduce results is made available in a git repository (Ricard and Gomez 2021).

The survey area covers three major Northwest Atlantic Fisheries Organization (NAFO) zones that divide the shelf into the colder east 4V and 4W (strata 440-466) and warmer west 4X (strata 470-495). Temporal trends are plotted by NAFO regions for several species. For each species, trends in geographic distribution and biomass or abundance are plotted. Some caution is required in interpreting the results obtained for several taxa due to low sample size as explained later in the text. The spatial extent of distribution is plotted over time to gauge how the area occupied has changed. The relationship between biomass and spatial extent reflects whether the species distribution expands when biomass increases. For each strata, the slope describing how local density varies with regional abundance was estimated (Myers and Stokes 1989). These slopes were then plotted against a habitat suitability index to identify important strata for each species. Then, length frequencies over time depicted any changes in mean size. The plots of condition over time revealed whether individual fish are fatter or thinner than their long term mean. Finally, depth, temperature and salinity preferences were estimated to gauge the range of environmental parameters (Perry and Smith 1994). A full ecological interpretation of trends is beyond the scope of this report. Other documents stemming from peer-reviewed scientific processes under the auspices of the Canadian Science Advisory Secretariat (CSAS) provide further descriptions of spatio-temporal trends in different indicators and put the information collected during the summer groundfish research vessel survey in a more focused context (see for example Clark and Emberley (2011)).

2 Methods

2.1 Survey Description

The survey is conducted annually in July-August and covers the Scotian Shelf and the Bay of Fundy (Figure 1). It normally involves two separate two-week trips on board an offshore fisheries vessel from the Canadian Coast Guard.

A number of changes in fishing gear type and vessels used occurred since the onset of sampling activities (Clark and Emberley 2011).

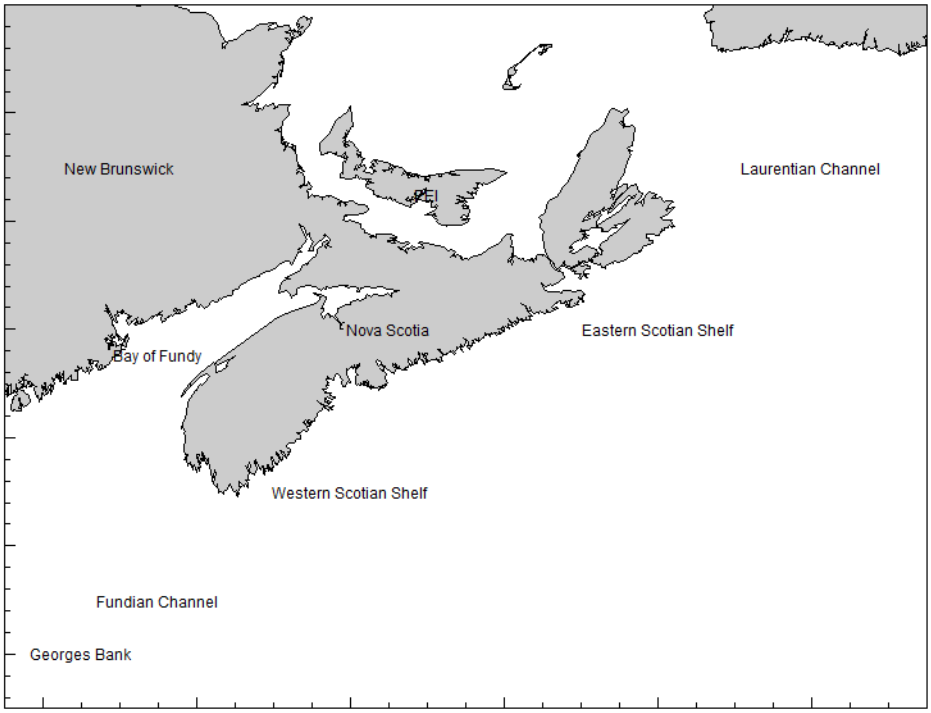

Figure 1. Map of the Scotian Shelf and Bay of Fundy.

2.2 Sampling Design

The summer survey covers divisions 4V, 4W and 4X of the Northwest Atlantic Fisheries Organization (NAFO) which includes the Scotian Shelf and the Bay of Fundy. The eastern limit of the survey is the Laurentian Channel and the western limit is the Fundian Channel (Figure 1).

The survey follows a stratified random design (Doubleday and Rivard 1981; Lohr 1999) (Figure 2). The number of tows conducted in each stratum is approximately proportional to its surface area.

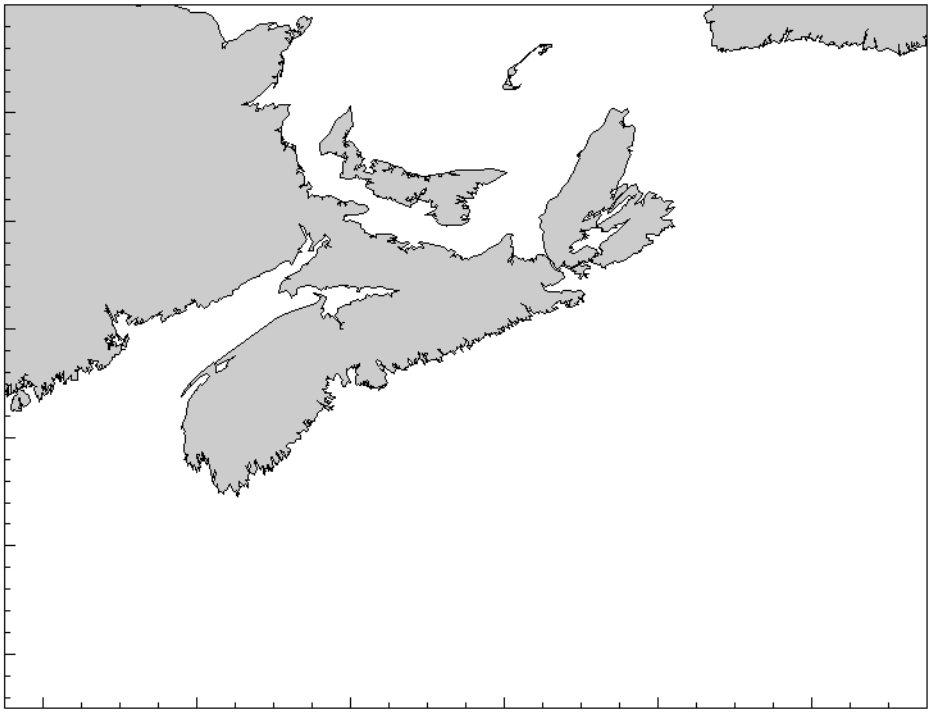

Figure 2. Map of the Summer survey strata.

The basic sampling unit of the survey is a 30-minute fishing tow conducted at a speed of 3.5 knots. This yields a distance towed of 1.75 nautical miles.

After each tow the catch is sorted by species and weighed. Each fish caught is then measured, and further sampling of individual fish weight, maturity status and age are performed for different length classes. When catches exceed 300 individuals, a random sub-sample is used to obtain the length and weight measurements.

The location of representative tows appears in Figure 3.

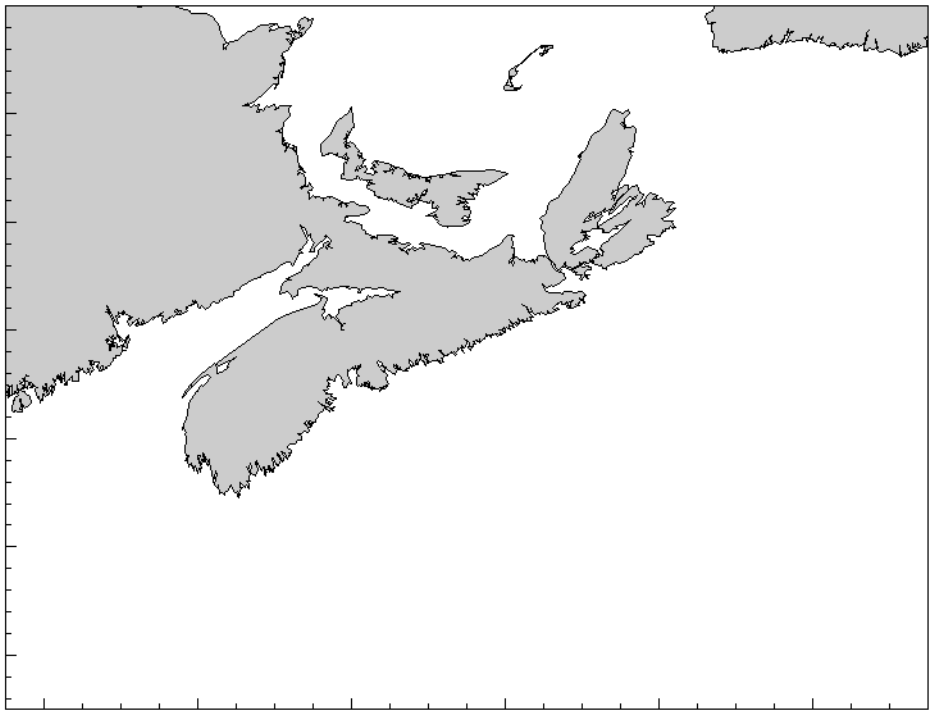

Figure 3. Map of the Summer survey tows.

2.3 Taxonomic Levels

Fish species caught during the surveys are identified by trained scientific personnel and their scientific name is determined. An internal species code used in the relational database is reported for each species (Losier and Waite 1989).

By its nature as a bottom trawl, the fishing gear used in the survey catches certain species better than others. To ensure that meaningful ecological information can be extracted from catch samples, we report the catch records for the subset of species that are caught reliably by the gear. To appear in this atlas, a species must have had a minimum of 10 observations over the duration of the survey activities. While both catch abundance and weight are recorded, the weight of species that appear at low abundances is often recorded as zero in the earlier parts of the survey when scales of appropriate precision were not available.

We divided the species caught into five categories based on 1) their taxonomic classification, 2) the number of recorded observations, and 3) their period of valid identification (Table 1). Category ”L”, for ”long”, was assigned to species that have more than 1000 records since 1970 and have been consistently identified since the onset of the survey. Category ”S”, for ”short”, was assigned to invertebrate species that were consistently sampled only since 1999 (Tremblay M. J. 2007). Category ”I”, for ”intermediate”, was assigned to species that had between 1000 and 200 catch records. Rare and elusive species (those with less than 200 catch records over the duration of the survey) are also reported but to a lower level of analytical details (Category ”LR”, for ”long rare”, and category ”SR”, for ”short rare”). The list of taxa covered in this document is presented in phylogenetic order (Nelson J. S. et al. 2004) in Table 2. To ensure concordance with authoritative taxonomic information, the AphiaID from the World Register of Marine Species is also provided in Table 2 (Appeltans et al. 2012).

Category	**Name**	**Description**
L	long	species that have more than 1000 records since 1970 and have been consistently identified since the onset of the survey
S	short	invertebrate species that were consistently sampled only since 1999
I	intermediate	species that had between 1000 and 200 catch records
LR	long rare	species with less than 200 catch records over the duration of the survey and that have been consistently identified since the onset of the survey
SR	short rare	species with less than 200 catch records and that were consistently sampled only since 1999

Table 1. Taxonomic levels

Table 2. List of species included in the Atlas. The species reported here are listed in phylogenetic order as per Page L. M. et al. (2013). For each taxonomic order and class, each species is listed in the table, its taxonomic family and scientific name is provided, along with its French and English common names, the species code used in the survey database, its AphiaID and a link to the World Registry of Marine Species, its number of catch records in the survey database and its classification category as defined in section 2.3.

	Family	Scientific name	English name	French name	Species code	AphiaID	Num. records	Ticket class
Myxini								
Myxiniformes	Myxinidae	*Myxine glutinosa*	Atlantic hagfish	Myxine du nord	241	101170	804	I
Petromyzonti								
Petromyzontiformes	Petromyzontidae	*Petromyzon marinus*	Sea lamprey	Lamproie marine	240	101174	16	LR
Actinopterygii								
Gadiformes	Gadidae	*Gadus morhua*	Atlantic cod	Morue franche	10	126436	5451	L
		Melanogrammus aeglefinus	Haddock	Aiglefin	11	126437	5827	L
	Phycidae	*Urophycis tenuis*	White hake	Merluche blanche	12	126504	3524	L
		Urophycis chuss	Red hake	Merluche écureuil	13	126503	2195	L
	Merlucciidae	*Merluccius bilinearis*	Silver hake	Merlu argenté	14	158962	4936	L
	Lotidae	*Brosme brosme*	Cusk	Brosme	15	126447	688	I
	Gadidae	*Pollachius virens*	Pollock	Goberge	16	126441	2787	L
		Microgadus tomcod	Atlantic tomcod	Poulamon atlantique	17	158928	44	LR
	Merlucciidae	*Merluccius albidus*	Offshore silver hake	Merlu argenté du large	19	158748	161	LR
Scorpaeniformes	Sebastidae	*Sebastes*	Atlantic redfishes	Sébastes de l'Atlantique	23	126175	4152	L
Pleuronectiformes	Pleuronectidae	*Hippoglossus hippoglossus*	Atlantic halibut	Flétan de l'Atlantique	30	127138	1634	L

	Family	Scientific name	English name	French name	Species code	AphiaID	Num. records	Ticket class
		Reinhardtius hippoglossoides	Greenland halibut	Flétan noir	31	127144	736	I
		Hippoglossoides platessoides	American plaice	Plie canadienne	40	127137	6023	L
		Glyptocephalus cynoglossus	Witch flounder	Plie grise	41	127136	4301	L
		Limanda ferruginea	Yellowtail flounder	Limande à queue jaune	42	158879	3233	L
		Pseudopleuronectes americanus	Winter flounder	Limande-plie rouge	43	158885	1632	L
	Paralichthyidae	*Citharichthys arctifrons*	Gulf Stream flounder	Plie du Gulf Stream	44	158791	382	I
Perciformes								
	Anarhichadidae	*Anarhichas lupus*	Atlantic wolffish	Loup atlantique	50	126758	1572	L
		Anarhichas minor	Spotted wolffish	Loup tacheté	51	126759	20	LR
		Anarhichas denticulatus	Northern wolffish	Loup à tête large	52	126757	17	LR
Clupeiformes								
	Clupeidae	*Clupea harengus*	Atlantic herring	Hareng de l'Atlantique	60	126417	3487	L
		Alosa sapidissima	American shad	Alose savoureuse	61	158670	468	I
		Alosa pseudoharengus	Alewife	Gaspareau	62	158669	977	I
Osmeriformes								
	Osmeridae	*Osmerus mordax*	Rainbow smelt	Éperlan arc-en-ciel	63	126737	59	LR
		Mallotus villosus	Capelin	Capelan	64	126735	540	I
Perciformes								
	Scombridae	*Scomber scombrus*	Atlantic mackerel	Maquereau commun	70	127023	696	I
Gadiformes								

	Family	Scientific name	English name	French name	Species code	AphiaID	Num. records	Ticket class
	Phycidae	*Phycis chesteri*	Longfin hake	Merluche à longues nageoires	112	158988	784	I
	Lotidae	*Enchelyopus cimbrius*	Fourbeard rockling	Motelle à quatre barbillons	114	126450	693	I
Perciformes								
	Labridae	*Tautogolabrus adspersus*	Cunner	Tanche-tautogue	122	159785	82	LR
Scorpaeniformes								
	Sebastidae	*Helicolenus dactylopterus*	Blackbelly rosefish	Sébaste chèvre	123	127251	610	I
Pleuronectiformes								
	Paralichthyidae	*Hippoglossina oblonga*	Fourspot flounder	Cardeau à quatre ocelles	142	158833	76	LR
	Scophthalmidae	*Scophthalmus aquosus*	Windowpane flounder	Turbot de sable	143	158907	115	LR
Aulopiformes								
	Chlorophthalmidae	*Parasudis truculenta*	Longnose greeneye	Oeil-vert à long nez	149	158868	45	LR
Myctophiformes								
	Myctophidae	*Myctophidae*	Lanternfishes	Poissons-lanternes	150	125498	160	LR
Aulopiformes								
	Chlorophthalmidae	*Chlorophthalmus agassizi*	Shortnose greeneye	Éperlan du large	156	126336	78	LR
Stomiiformes								
	Sternoptychidae	*Maurolicus muelleri*	Silvery lightfish	Brossé améthyste	158	127312	52	LR
	Stomiidae	*Stomias boa*	Boa dragonfish	Dragon-boa	159	127374	20	LR
Argentiniformes								
	Argentinidae	*Argentina silus*	Greater argentine	Grande argentine	160	126715	963	I
Scorpaeniformes								
	Cottidae	*Myoxocephalus octodecemspinosus*	Longhorn sculpin	Chaboisseau à dix-huit épines	300	159520	3292	L

	Family	Scientific name	English name	French name	Species code	AphiaID	Num. records	Ticket class
		Myoxocephalus scorpius	Shorthorn sculpin	Chaboisseau à épines courtes	301	127203	131	LR
		Myoxocephalus aenaeus	Grubby	Chaboisseau bronzé	303	159519	40	LR
		Triglops murrayi	Moustache sculpin	Faux-trigle armé	304	127205	1182	L
		Artediellus uncinatus	Arctic hookear sculpin	Hameçon neigeux	306	127195	306	I
	Psychrolutidae	*Cottunculus microps*	Polar sculpin	Cotte polaire	307	127235	29	LR
	Cottidae	*Icelus spatula*	Spatulate sculpin	Icèle spatulée	314	127200	40	LR
	Hemitripteridae	*Hemitripterus americanus*	Sea raven	Hémitriptère atlantique	320	159518	2126	L
	Agonidae	*Aspidophoroides monopterygius*	Alligatorfish	Poisson-alligator atlantique	340	159459	1029	L
		Ulcina olrikii	Arctic alligatorfish	Poisson-alligator arctique	341	274356	13	LR
		Leptagonus decagonus	Atlantic poacher	Agone atlantique	350	127191	266	I
		Agonidae	Alligatorfishes	Poissons-alligator	351	125588	43	LR
Lophiiformes	Lophiidae	*Lophius americanus*	Monkfish	Baudroie d'Amérique	400	159184	1970	L
Gadiformes	Macrouridae	*Nezumia bairdii*	Marlin-spike grenadier	Grenadier du Grand Banc	410	183289	529	I
		Trachyrincus murrayi	Roughnose grenadier	Grenadier-scie	412	126481	18	LR
		Coryphaenoides rupestris	Roundnose grenadier	Grenadier de roche	414	158960	17	LR
Scorpaeniformes	Cyclopteridae	*Cyclopterus lumpus*	Lumpfish	Lompe	501	127214	216	I

	Family	Scientific name	English name	French name	Species code	AphiaID	Num. records	Ticket class
		Eumicrotremus spinosus	Atlantic spiny lumpsucker	Petite poule de mer atlantique	502	127217	226	I
	Liparidae	*Liparis atlanticus*	Atlantic seasnail	Limace atlantique	503	159524	34	LR
		Liparis fabricii	Gelatinous snailfish	Limace gélatineuse	505	127218	27	LR
		Liparis gibbus	Variegated snailfish	Limace marbée	512	159526	41	LR
		Careproctus reinhardti	Sea tadpole	Petite limace de mer	520	127212	18	LR
Perciformes	Zoarcidae	*Lycenchelys verrillii*	Wolf eelpout	Lycode à tête longue	603	159258	40	LR
Anguilliformes	Nemichthyidae	*Nemichthys scolopaceus*	Slender snipe eel	Avocette ruban	604	126306	28	LR
Perciformes	Ammodytidae	*Ammodytes dubius*	Sand lance	Lançon	610	151520	1283	I
	Zoarcidae	*Lycodes terraenovae*	Newfoundland eelpout	Lycode du Labrador	619	127117	64	LR
		Lycodes lavalaei	Newfoundland eelpout	Lycode du Labrador	620	127107	72	LR
	Pholidae	*Pholis gunnellus*	Rock gunnel	Sigouine de roche	621	126996	21	LR
	Stichaeidae	*Lumpenus lampretaeformis*	Snakeblenny	Lompénie-serpent	622	154675	423	I
		Leptoclinus maculatus	Daubed shanny	Lompénie tachetée	623	127072	443	I
		Ulvaria subbifurcata	Radiated shanny	Ulvaire deux-lignes	625	159821	145	LR
		Eumesogrammus praecisus	Fourline snakeblenny	Quatre-lignes atlantique	626	159817	40	LR
	Cryptacanthodidae	*Cryptacanthodes maculatus*	Wrymouth	Terrassier tacheté	630	159675	120	LR
	Callionymidae	*Foetorepus agassizii*	Spotfin dragonet	Dragonnet tacheté	637	276339	20	LR

	Family	Scientific name	English name	French name	Species code	AphiaID	Num. records	Ticket class
	Zoarcidae	*Zoarces americanus*	Ocean pout	Loquette d'Amérique	640	159267	1478	L
		Lycodes reticulatus	Arctic eelpout	Lycode arctique	641	127112	70	LR
		Melanostigma atlanticum	Atlantic soft pout	Molasse atlantique	646	127120	43	LR
		Lycodes vahlii	Vahl's eelpout	Lycode à carreaux	647	127118	565	I
	Stromateidae	*Peprilus triacanthus*	Atlantic butterfish	Stromaté fossette	701	159828	487	I
Zeiformes								
	Zeidae	*Zenopsis conchifer*	Silvery John dory	Saint Pierre argenté	704	127426	39	LR
Aulopiformes								
	Paralepididae	*Arctozenus risso*	White barracudina	Lussion blanc	712	126352	196	LR
Beloniformes								
	Scomberesocidae	*Scomberesox saurus*	Atlantic saury	Balaou atlantique	720	126392	37	LR
Stomiiformes								
	Sternoptychidae	*Sternoptychidae*	Hatchetfishes	Haches d'argent	741	125603	21	LR
Lophiiformes								
	Ogcocephalidae	*Dibranchus atlanticus*	Atlantic batfish	Malthe atlantique	742	126558	18	LR
Pleuronectiformes								
	Cynoglossidae	*Symphurus diomedeanus*	Spottedfin tonguefish	Langue fil noir	816	159358	24	LR
Scorpaeniformes								
	Cottidae	*Artediellus atlanticus*	Atlantic hookear sculpin	Hameçon atlantique	880	127193	258	I
Elasmobranchii								
Rajiformes								
	Rajidae	*Dipturus laevis*	Barndoor skate	Grande raie	200	158548	246	I
		Amblyraja radiata	Thorny skate	Raie épineuse	201	105865	3937	L
		Malacoraja senta	Smooth skate	Raie lisse	202	158554	1773	L

	Family	Scientific name	English name	French name	Species code	AphiaID	Num. records	Ticket class
		Leucoraja erinacea	Little skate	Raie hérisson	203	158551	712	I
		Leucoraja ocellata	Winter skate	Raie tachetée	204	158553	1180	L
Squaliformes								
	Squalidae	*Squalus acanthias*	Picked dogfish	Aiguillat commun	220	105923	1985	L
	Etmopteridae	*Centroscyllium fabricii*	Black dogfish	Aiguillat noir	221	105906	31	LR
Cephalopoda								
Oegopsida								
	Ommastrephidae	*Illex illecebrosus*	Northern shortfin squid	Encornet rouge nordique	4511	153087	4836	L
Myopsida								
	Loliginidae	*Doryteuthis pealeii*	Longfin inshore squid	Calmar totam	4512	574541	96	LR
Malacostraca								
Decapoda								
	Pandalidae	*Pandalus borealis*	Northern prawn	Crevette nordique	2211	107649	718	S
	Cancridae	*Cancer borealis*	Jonah crab	Tourteau jona	2511	158056	1387	S
		Cancer irroratus	Atlantic rock crab	Tourteau poïnclos	2513	158057	788	S
	Oregoniidae	*Hyas coarctatus*	Arctic lyre crab	Crabe Hyas coarctatus	2521	107323	711	S
	Lithodidae	*Lithodes maja*	Atlantic king crab	Crabe épineux du nord	2523	107205	531	S
	Oregoniidae	*Chionoecetes opilio*	Queen crab	Crabe des neiges	2526	107315	1546	S
		Hyas araneus	Great spider crab	Crabe lyre araignée	2527	107322	625	S
	Geryonidae	*Chaceon quinquedens*	Red deepsea crab	Crabe rouge	2532	158407	33	SR
	Nephropidae	*Homarus americanus*	American lobster	Homard américain	2550	156134	1623	S

2.4 Analyses

The Oracle relational database where all data are stored was accessible from the Bedford Institute of Oceanography in Dartmouth, Nova Scotia. Structured Query Language (SQL) is used to extract the data from the production server and to create the data products used in all subsequent analyses. Catch records classified as ”valid” (i.e. a representative tow without damage to the net) are used in the current analyses. To make the available samples comparable, catch number and weight for each species was standardized for the distance towed.

All data processing and analyses were conducted using the R software (R Core Team 2020) using packages gstat (Pebesma 2004), PBSmapping (Schnute et al. 2019), RODBC (Ripley and Lapsley 2019), spatstat (Baddeley 2015), maptools (Bivand and Lewin-Koh 2020), rgeos (Bivand and Rundel 2020), classInt(Bivand 2020), RColorBrewer(Neuwirth 2014), MASS (Ripley et al. 2020), worms (Holstein 2018), and tidyverse (Wickham 2019).

2.4.1 Geographic distribution of catches

Spatial interpolation of catch biomass (kg/tow) or abundance (number/tow) was done using a weighting inversely proportional to the distance, using function ”idw” of the spatstat R package (Baddeley 2015).

2.4.2 Abundance and biomass indices

For each species, stratified random estimates of catch abundance and biomass (Smith 1996) are computed for each year. Yearly estimates of the standard error were also computed.

2.4.3 Distribution indices

For each Category L, I and S fish species, the minimum area required to account for 75% and 95% of the total biomass or abundance were computed (D75% and D95%). These measures of distributions were computed for each year by using the Lorenz curve of mean stratum-level catch estimates and the area of occupied strata (Swain and Sinclair 1994; Swain and Morin 1996).

2.4.4 Length frequencies

The length frequency distribution of catch is tabulated for each seven-year period (1970-2009), and last ten-year period (2010-2020).

2.4.5 Length-weight relationship and condition factor

The relationship between the weight and the length of fish was estimated using the following non-linear isometric relationship:

$$W = \alpha L^{\beta}$$

where W is the total weight (g), L is the length (cm), and, α and β are the parameters to be estimated.

Average fish condition (C) is computed as:

$$C = \frac{W}{\alpha L^{\beta}}$$

2.4.6 Depth, temperature and salinity distribution of catches

For each category L species, We followed the methods developed by (Perry and Smith 1994) and generated cumulative frequency distributions of depth, temperature and salinity of survey catches.

2.4.7 Density-dependent habitat selection

We follow the methods of (Myers and Stokes 1989) to evaluate how fish abundance in each stratum varied with overall temporal fluctuations of population abundance.

For each category L species, we fitted a model of the relationship between stratum-level density and overall abundance (the yearly stratified random estimate of abundance, defined above). To properly use the observations of zero catch while accounting for the logarithmic distribution of catch abundance, we implemented the model as a generalised linear using a log link and a Poisson error distribution:

$$Y_{h,i} = \alpha_h Y_i^{\beta_h}$$

where, $y_{h,i}$ is the average abundance of stratum h in year i, and $\alpha_{h,i}$ and $\beta_{h,i}$ are the fitted parameters. The estimated parameter $\beta_{h,i}$ is referred to as the "slope parameter" and indicates whether stratum-level density is positively ($\beta_{h,i} <= 0$), negatively ($\beta_{h,i} >= 0$) or negligibly ($\beta_{h,i} \approx 0$) related to population abundance.

To estimate the suitability of each stratum, the median abundance observed during the years that are in the top 25% of yearly estimates is used. We combine the slope parameter estimates

from the above model with the median abundance to identify strata that have consistently high abundance and whose local density is weakly related to fluctuation in population abundance ($\beta_{h,i} \approx 0$). Preferred strata are identified for each category L species.

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